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Comparative Study of Different Codes in Seismic Assessment

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Abstract - *This study focuses on comparison of International standards. The chosen standards are Eurocode, IBC (American Society of civil Engineers) and Indian code i.e. IS 1893:2002. The study also helps in understanding the main contributing factors which lead to poor performance of Structure during the earthquake, so as to achieve their adequate safe behavior under future earthquakes. The structure analysed is symmetrical, G+10, Special RC moment-resting frame (SMRF). Modelling of the structure is done as per staad pro. V8i software. Time period of the structure in both the direction is taken from the software and as per the three standards three models are made. The Lateral seismic forces are calculated manually. The Lateral seismic forces are calculated per floor as per different codes in X and Z direction and are applied to the Centre of gravity of the structure. The analytical results of the model buildings are then represented graphically and in tabular form, it is compared and analysed taking note of any significant differences. This study focuses on exploring variations in the results obtained using the three codes i.e. Eurocode, IBC (ASCE) and Indian code. A comparative analysis is performed in terms of Base shear, Displacement, Axial load, Moments in Y and Z direction for selected columns and also comparing Displacement, Axial load, Moments in Y and Z direction Floor wise of different codes for same selected columns. Accompanied by comparative analysis of Displacement, shear Y, Torsion and Moment Z of selected beams on each floor for different international codes.*

Key Words: International building code (IBC), American Society of civil Engineers (ASCE), Eurocode, Indian code IS 1893:2002 and SMRF.

1. INTODUCTION

1.1 Overview

Natural calamities such as earthquakes, Tsunamis, Landslides, Floods etc. causes severe damage and suffering to human being by collapsing many structures, trapping or killing persons, cutting off transport systems, blocking of navigation systems, animals hazards etc. Such natural disasters are big challenges to the progress of development. However, civil engineers play a major role in minimizing the damages by proper designing the structures or by proper material selections or proper constructions procedure and taking other useful decisions. This includes understanding the earthquakes, behavior of the materials of construction and structures and the extent to which structural engineers make use of the knowledge in taking proper decisions in designing the structures made of reinforced concrete.

Earthquakes are defined as a vibration of the earth's surface that occurs after a release of energy in the earth's crust. Because the earth's crust is made up of numerous plates that are constantly moving slowly, vibrations can occur which result in small earthquakes. Most earthquakes are small but are not readily felt. Larger and violent earthquakes are those which occur in a release of energy as the plates slide past or collide into one another. The characteristics such as intensity, duration, etc. of seismic ground vibrations expected at any location depend upon the magnitude of earthquake, its depth of focus, distance from the epicenter, characteristics of the path through which the seismic waves travel, and the soil strata on which the structure stands. The predominant direction of ground vibration is usually horizontal.

Reinforced concrete Special moment frames are used as part of seismic force resisting systems in buildings that are designed to resist earthquakes. Beams and columns in moment frames are proportioned and detailed in such a manner that they must resist flexural, axial, and shearing actions that result as a building sways through multiple displacement cycles during strong earthquake ground shaking. Special proportioning and detailing requirements are responsible for frame, capable of resisting strong earthquake shaking without significant loss of stiffness or strength. These moment-resisting frames are called "Special Moment Frames" because of these additional requirements, which improve the seismic resistance in comparison with less detailed Intermediate and Ordinary Moment Frames.

Twist in buildings, called torsion, makes different portions at the same floor level to move horizontally by different amounts. This induces more damage in the frames and walls on the side that moves more. Many buildings have been severely affected by this excessive torsional behavior during past earthquakes. It is best to minimize if not completely avoid. This twist can be minimized by ensuring that buildings have symmetry in plan i.e., uniformly distributed mass and uniformly placed lateral load resisting systems. If this twist cannot be avoided, special calculations need to be done to account for this additional shear forces in the design of buildings; the Indian seismic code (IS 1893, 2002), Eurocode and IBC (ASCE) has provisions for such calculations. But, for sure, these buildings with twist will perform poorly during strong earthquake shaking.[13]

Seismic building codes are guidelines to design and construct the buildings and civil engineering works in seismic regions. Reasons behind is to protect human lives from worst conditions which occurs during earthquake, to limit damage, and to sustain operations of important structures for civil protection. Seismic design has progressed significantly over the year due to the contribution of practicing engineers, as well as academic and governmental researchers. The progress depends on the improvement of the representation of ground motion, soil type and structure.

1.2 Objective of the Project:

The main objective of this project is to bring out the main contributing factors which lead to poor performance during the earthquake and make recommendations which should be taken into account in designing the multistoried reinforced concrete buildings so as to achieve their adequate safe behavior under future earthquakes. Earthquake codes have been revised and updated depending on the improvements in the representation of ground motions, soils and structures. The Indian Standard Code IS: 1893 was suitably updated in 2002 so as to address the various design issues brought out in the earthquake behavior of the RC Buildings.

The chosen standards are Indian Standard Code IS: 1893, Eurocode 8 and International building code (ASCE). A comparative analysis was performed in terms of Base shear, Displacement, Axial load, Moments in Y and Z direction for selected columns and also comparing Displacement, Axial load, Moments in Y and Z direction Floor wise of different codes for same selected columns. Accompanied by comparative analysis of Displacement, shear Y, Torsion and Moment Z of selected beams on each floor for different codes.

1.3 Methodology:

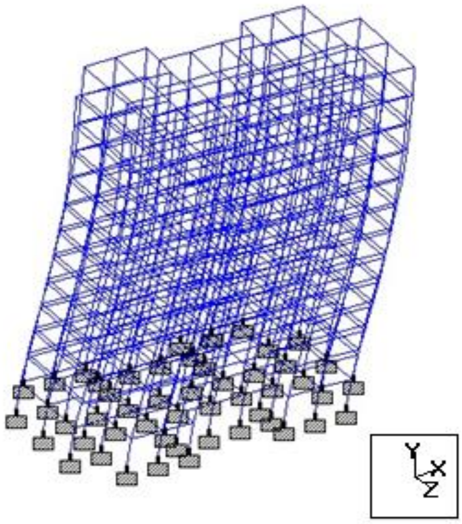
The methodology worked out to achieve the mentioned objectives is as follows:

1. Modeling of the selected building in Staad pro. V8i Software.
2. Retrieved time period of structure from the software.
3. Three models as per the codes i.e. Indian code, Eurocode, IBC (ASCE) specification were made.
4. Applied manually calculated Lateral seismic forces and load combinations as per IS 1893-2002, Eurocode and IBC (ASCE).
5. Analysed the models and graphical and tabular representation of the data is presented.

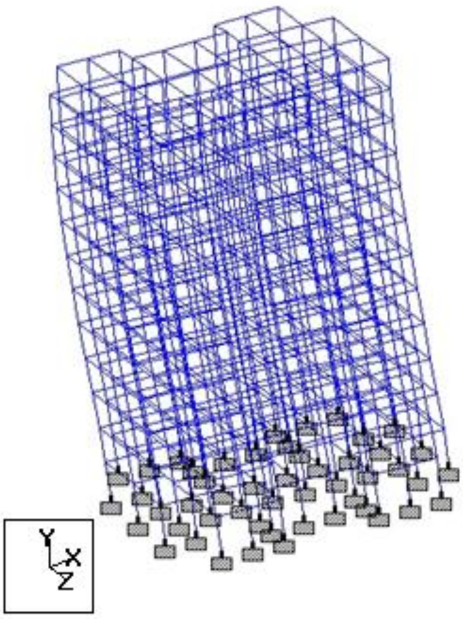
1.3.1 Time period:

The equivalent static methods adopt seismic coefficient, which depends on the natural time period of their vibration of the structure, the time period is required for earthquake resistance design of the structures and to calculate the base shear. Time period of the structure is been taken from the software Staad pro.

Time period in sec:



For X direction: 0.756



For Z direction: 1.005

These values of time period of the structure is taken and the base shear for Indian code, Eurocode and IBC is calculated respectively in both X and Z direction.

1.3.2 Distribution of the horizontal seismic forces:

Different load calculation and base shear calculation procedure has been adopted for different codes as specified in the respective codes. i.e. IS 1893-2002, Eurocode and IBC (ASCE). The base shear is calculated and is distributed along the height of the building at each floor. The lateral seismic force (kN) induced at any level is determined as specified in the codes.

Indian standards IS-1893:2002:

IS 1893:2002 is denoted as "Criteria for earthquake resistant Design of structures" Part 1 General provisions and buildings.

Vertical Distribution of Base Shear to Different Floor Levels is stated in IS 1893:2002.The design lateral force shall first be computed for the building as a whole. The design lateral force shall then be distributed to the various floor levels. This overall design seismic force thus obtained at each floor level shall then be distributed to individual lateral load resisting elements depending on the floor diaphragm action.

The design base shear calculated shall be distributed along the height of the building as per the following expression:

$$Q_i = V_B \frac{W_i h_i^k}{\sum_{j=1}^{n} W_j h_j^k}$$

Euro Code 8 EN 1998-1:2004:

Eurocode 8, denoted as EN 1998: "Design of structures for earthquake resistance" which is used in design and construction of buildings and civil engineering works in seismic regions. Base shear of the structure calculated as stated by expression (EN 1998-1/4.5). Distribution of the horizontal seismic forces can be calculated by two ways

a) Depend on height of masses
b) Depend on absolute horizontal displacement of masses

Distribution of the horizontal seismic forces is calculated as per height of masses and is computed as per the following expression:

$$F_i = F_b \cdot \frac{z_i \cdot m_i}{\Sigma z_j \cdot m_j}$$

IBC (ASCE – 7):

ASCE is American Society of Civil Engineers and ASCE -7 "Minimum Design Loads for Buildings and Other Structures" is the Standard which provides requirements for dead, live, soil, Flood, wind, snow, rain, ice, and earthquake loads, and their combinations that are suitable for inclusion in building codes and is used in design of building.

Seismic Base Shear is calculated as per Eq. 9.5.5.2-1 of ASCE-7. And the lateral seismic force *(Fx)* (kip or kN) induced at any level is determined from the following equations:

$$F_x = C_{vx} V$$

And

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

Lateral seismic forces Calculated per floor as per different codes in X direction:

Table-1.1: Lateral seismic forces in X direction

X Direction			
Floor	Indian code (KN)	Eurocode (KN)	IBC (ASCE) (KN)
G.F	2.535	29.098	15.91
1ST	13.466	77.60	47.11
2ND	30.298	116.40	74.39
3RD	53.86	155.209	102.90
4TH	84.163	194.011	132.46
5TH	121.194	232.81	162.63
6TH	164.959	271.61	193.42
7TH	215.457	310.42	225.03
8TH	272.687	349.22	257.06
9TH	336.65	388.02	289.51
10TH	407.348	426.83	322.36
11TH	484.778	311.34	243.01

Lateral seismic forces Calculated per floor as per different codes in Z direction:

Table-1.2: Lateral seismic forces in X direction

Z Direction			
Floor	Indian code (KN)	Eurocode (KN)	IBC (ASCE) (KN)
G.F	1.9069	21.82	9.31
1ST	10.1297	58.20	29.94
2ND	22.7918	87.30	49.65
3RD	40.5188	116.41	71.22
4TH	63.31	145.51	94.18
5TH	91.167	174.61	117.92
6TH	124.088	203.71	142.75
7TH	162.075	232.81	169.44
8TH	205.126	261.91	196.44
9TH	253.24	291.017	224.06
10TH	306.423	320.12	252.45
11TH	364.669	233.51	192.25

These lateral seismic forces, calculated by different codes are applied on the Centre of gravity of the structure at each floor. The forces are applied on Centre of gravity of each floor slab in both the directions. i.e. X and Z Directions. The horizontal lateral forces are manually calculated and are applied to the structure by using software Staad pro.

1.3.3 Specifications:

The specifications used in modeling are

Table-1.3: Specifications used in modeling

Sr. No	Parameters	Dimensions/Type
1	Plan dimension	27 x 17 m
2	Number of stories	G+10
3	Total height of building	36m
4	Height of each storey	3m
5	Column size	600 X 350 mm
6	Beam size	500 x 300 mm
7	Grade of concrete	M20
8	Frame type	SMRF
9	Soil type	Medium soil
10	Live load	2.5 KN/m
11	Inner wall	150 mm
12	Outer wall	250 mm
13	Slab thickness	150mm
14	Unit weights of Concrete	25 KN/Cum
15	Unit weights of brick work	19 KN/Cum

1.3.4 Modeling:

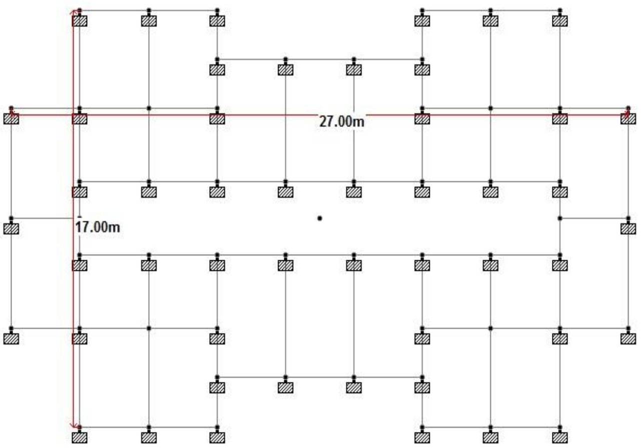


Fig-1: Plan of the selected building

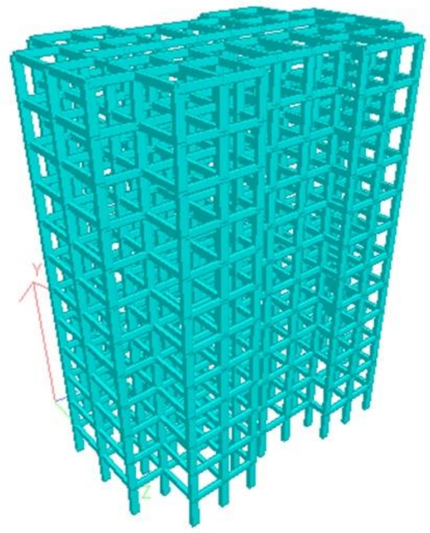


Fig-2: 3D View of the selected building

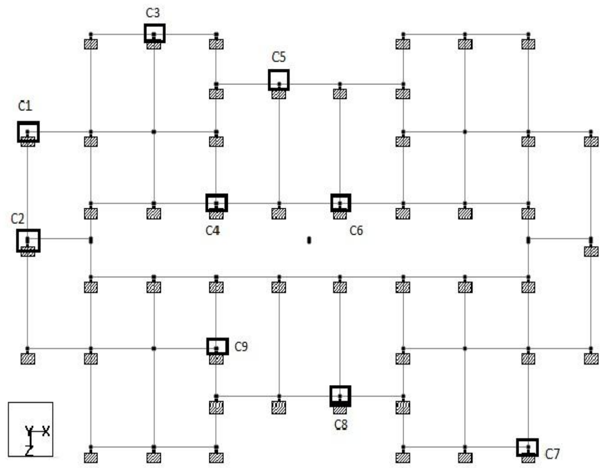


Fig-3: Selected Column

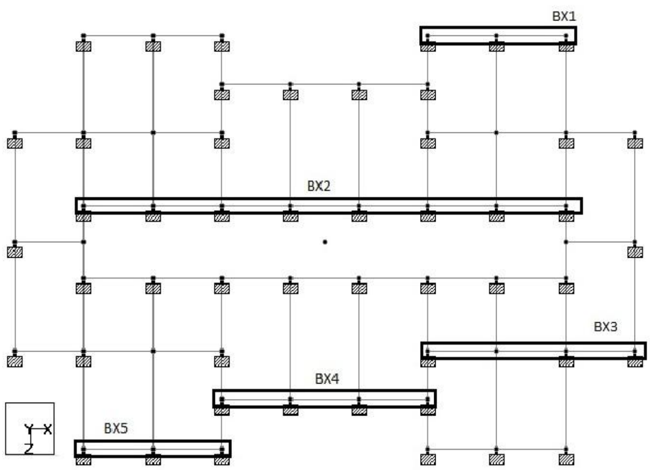


Fig-4: Selected Beam in X Direction

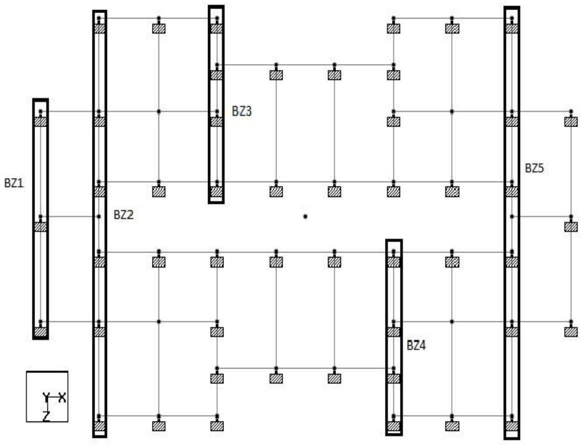


Fig-5: Selected Beam in Z Direction

2 ANALYSIS AND RESULTS

2.1 OVERVIEW

A G+10 building is analysed with three different code specifications during the earthquake. Parameters like base shear, displacement, axial force, bending moments, for column is calculated and shear, moment, displacement and torsion for beam is calculated. Graphical and Tabular representation of data is discussed in this chapter.

2.2 Base Shear

2.2.1 In X Direction

Table-1: Base shear for earthquake in X-direction

Different Codes	Base Shear in X direction (KN)
IBC	2066.45
India Code	2187.4046
Eurocode	2862.6

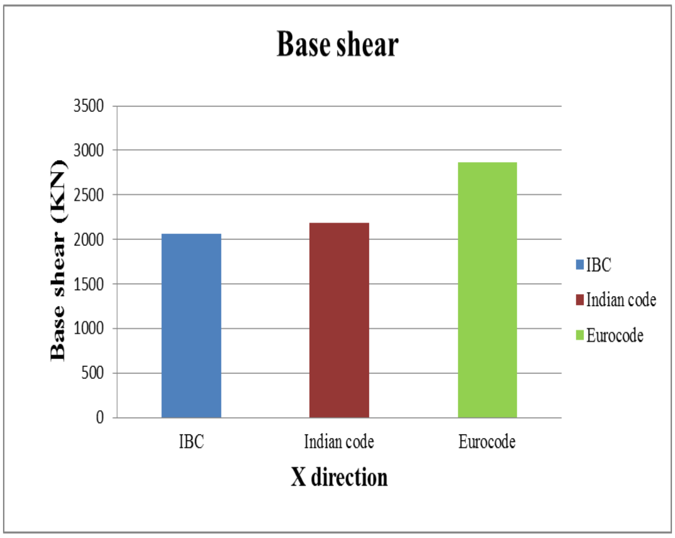


Fig-2.2.1: Base Shear for earthquake in X-direction

2.2.2 In Z Direction

Table-2: Base shear for earthquake in Z-direction

Different Codes	Base Shear in Z direction (KN)
IBC	1551.67
Indian Code	1645.4506
Eurocode	2146.95

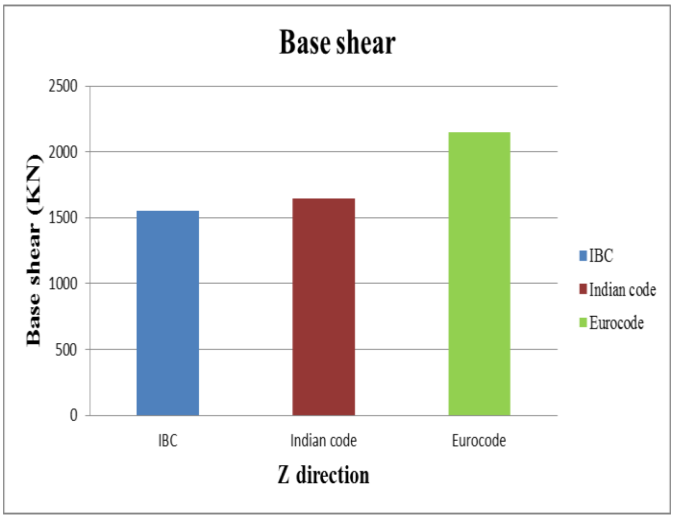


Fig-2.2.2: Base shear for earthquake in Z-direction

2.3 Column

2.3.1 Maximum Displacement on each column

Table-3: Maximum Displacement on each column

No. of column	Maximum Displacement on each column		
	EUROCODE	INDIAN CODE	IBC
	(mm)	(mm)	(mm)
C1	48.426	62.855	35.838
C2	48.448	62.895	35.99
C3	48.397	62.885	35.844
C4	48.572	63.164	36.275
C5	48.417	62.935	35.979
C6	48.626	63.249	36.409
C7	48.393	62.822	35.75
C8	48.418	62.935	35.979
C9	48.374	62.858	35.943
Maximum Displacement	48.626	63.249	36.409

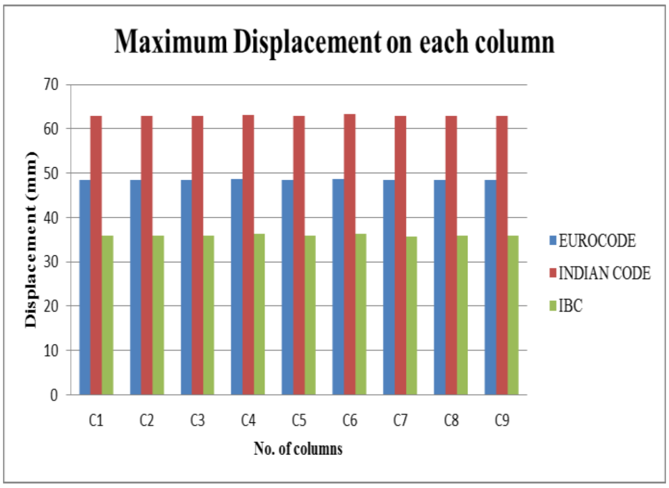


Fig-2.3.1: Maximum Displacement on each column

2.3.2 Maximum Displacement

Table-4: Maximum Displacement

Different Codes	Maximum Displacement(mm)
EUROCODE	48.626
INDIAN CODE	63.249
IBC	36.409

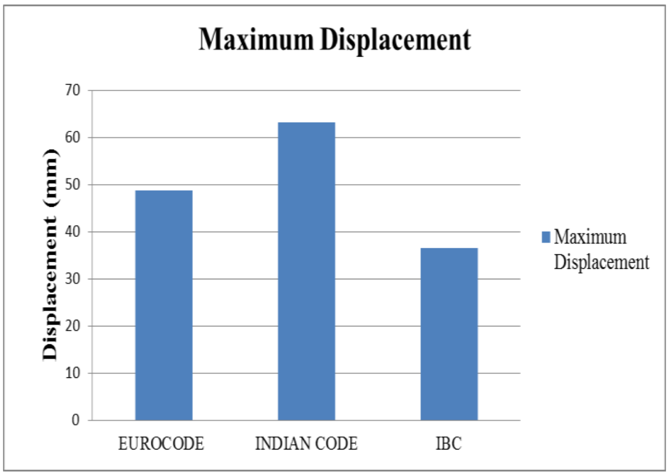


Fig-2.3.2: Maximum Displacement

2.3.3 Maximum Axial Force on each column

Table-5: Maximum Axial Force on each column

No. of column	Maximum Axial Force on each column		
	EUROCODE (KN)	INDIAN CODE (KN)	IBC (KN)
C1	1973.552	2572.874	2054.179
C2	2463.333	2885.308	2389.766
C3	2061.08	2416.511	2002.494
C4	2508.583	2856.556	2432.575
C5	2323.181	2548.002	2160.538
C6	2736.804	2991.436	2563.915
C7	1800.722	2338.237	1867.721
C8	2323.181	2548.002	2160.538
C9	2380.737	2605.192	2180.325
Maximum axial force (kN)	2736.804	2991.436	2563.915

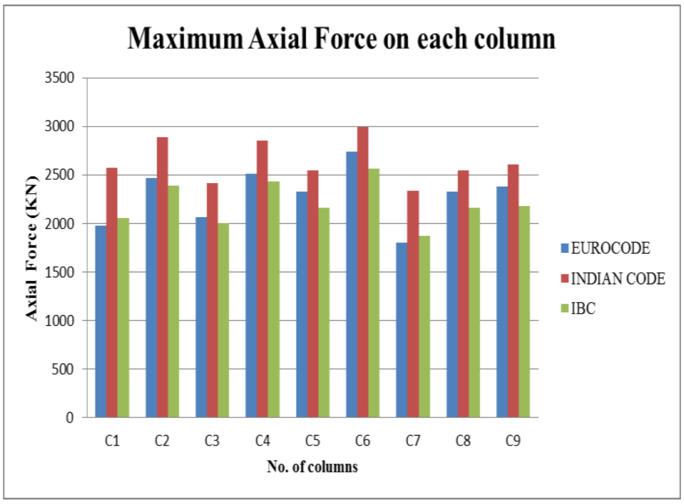


Fig-2.3.3: Maximum Axial Force on each column

2.3.4 Maximum axial force (KN)

Table-6: Maximum Axial force

Different codes	Maximum axial force (KN)
EUROCODE	2736.804
INDIAN CODE	2991.436
IBC	2563.915

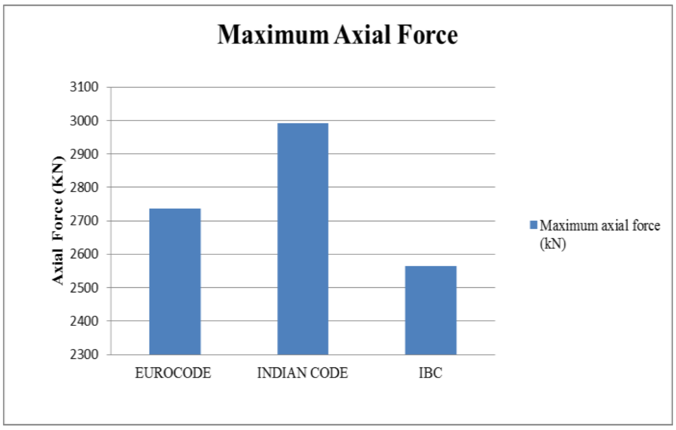


Fig-2.3.4: Maximum Axial force

2.3.5 Maximum Moment-Y on each column

Table-7: Maximum Moment-Y on each column

No. of columns	Maximum Moment-Y on each column		
	EUROCODE (KNm)	INDIAN CODE (KNm)	IBC (KNm)
C1	79.06	92.78	60.39
C2	85.37	98.495	61.691
C3	81.01	95.943	68.344
C4	79.13	91.985	59.03

C5	83.701	98.976	70.523
C6	82.568	97.621	65.644
C7	79.652	93.169	63.396
C8	83.701	98.976	70.523
C9	106.99	128.19	84.834
Maximum Moment -Y	106.99	128.19	84.834

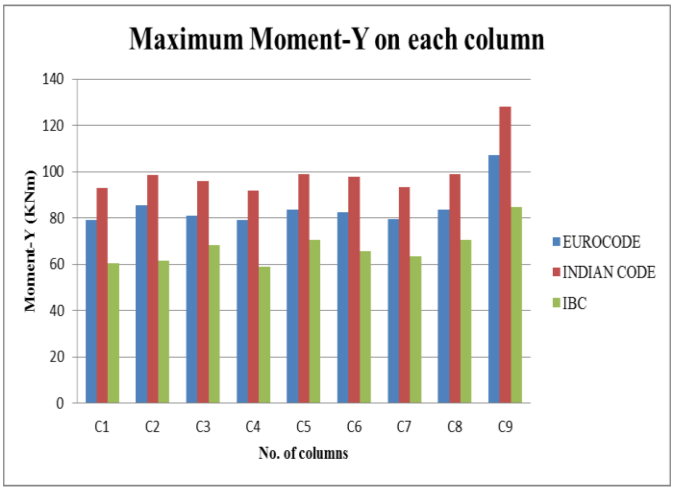


Fig-2.3.5: Maximum Moment-Y on each column

2.3.6 Maximum Moment-Y

Table-8: Maximum Moment-Y

Different codes	Maximum Moment-Y(KNm)
EUROCODE	106.99
INDIAN CODE	128.19
IBC	84.834

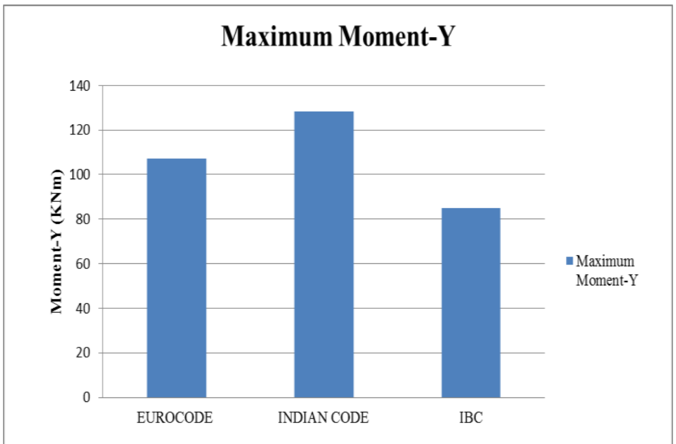


Fig-2.3.6: Maximum Moment-Y

2.3.7 Maximum Moment-Z on each column

Table-9: Maximum Moment-Z on each column

No. of column	Maximum Moment-Z on each column		
	EUROCODE (KNm)	INDIAN CODE (KNm)	IBC (KNm)
C1	121.54	140.65	89.664
C2	117.56	136.266	87.362
C3	135.365	155.577	97.831
C4	133.365	153.517	96.304
C5	135.18	155.732	97.919
C6	134.4	154.849	97.329
C7	121.445	140.56	89.57
C8	135.18	155.732	97.919
C9	126.256	148.353	99.248
Maximum Moment-Z	135.365	155.732	99.248

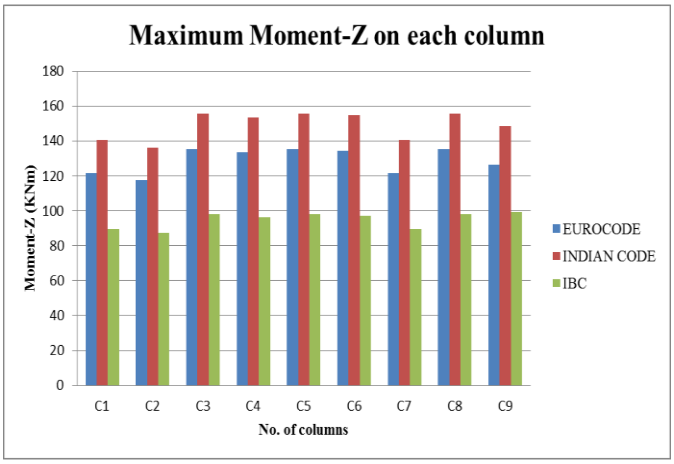


Fig-2.3.7: Maximum Moment-Z on each column

2.3.8 Maximum Moment-Z

Table-10: Maximum Moment-Z on each column

Different codes	Maximum Moment-Z (KNm)
EUROCODE	135.365
INDIAN CODE	155.732
IBC	99.248

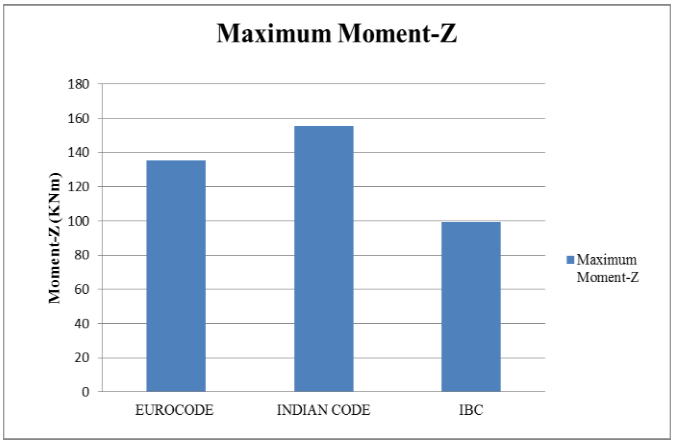


Fig-2.3.8: Maximum Moment-Z

2.4 Floor wish comparison

2.4.1 Maximum Displacement on each Floor

Table-11: Maximum Displacement on each Floor

Height (m)	Maximum Displacement on each Floor		
	Eurocode (mm)	IBC (mm)	Indian (mm)
0	0	0	0
3	3.878	3.065	4.234
6	9.234	7.022	10.245
9	14.712	11.049	16.534
12	20.096	15.013	22.91
15	25.277	18.844	29.269
18	30.165	22.476	35.504
21	34.669	25.844	41.492
24	38.704	28.881	47.095
27	42.188	31.518	52.164
30	45.04	33.687	56.532
33	47.19	35.326	60.02
36	48.626	36.409	62.477

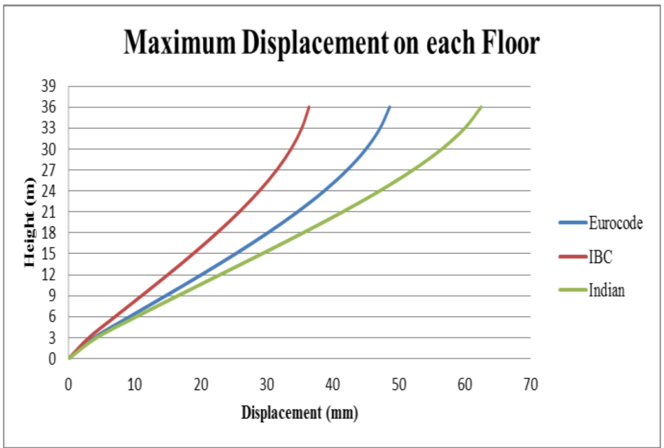


Fig-2.4.1: Maximum Displacement on each floor

2.4.2 Maximum Axial force on each floor

Table-12: Maximum Axial force on each floor

Height (m)	Maximum Axial force on each floor		
	INDIAN CODE (KN)	EUROCODE (KN)	IBC (KN)
0	2991.436	2736.804	2563.915
3	2715.355	2483.952	2323.625
6	2443.458	2234.962	2084.523
9	2175.167	1989.298	1848.192
12	1909.846	1746.376	1614.897
15	1646.983	1505.722	1384.818
18	1386.12	1266.911	1160.639
21	1126.843	1029.564	942.554
24	868.769	793.324	725.499
27	611.564	557.881	509.182
30	355.044	323.343	298.221
33	114.894	103.56	104.284

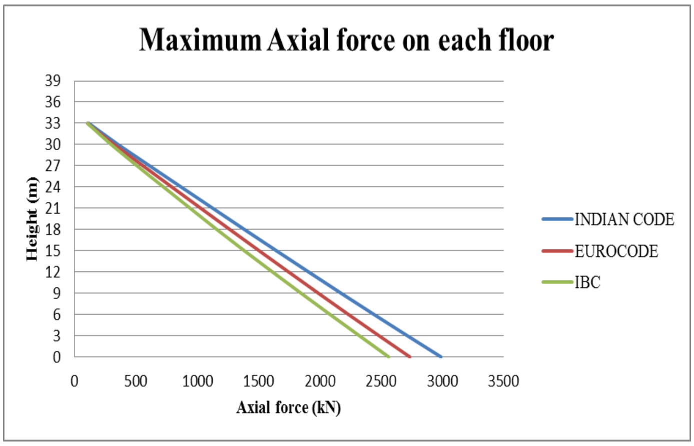


Fig-2.4.2: Maximum Axial force on each floor

2.4.3 Maximum Moment-Y on each Floor

Table-13: Maximum Moment-Y on each floor

Height (m)	Maximum Moment-Y on each Floor		
	INDIAN (KNm)	EUROCODE (KNm)	IBC (KNm)
0	106.968	92.587	68.144
3	126.414	108.18	82.654
6	127.35	106.99	83.939
9	128.578	105.563	84.834
12	127.728	101.99	84.035
15	125.257	96.617	81.732
18	120.497	89.532	77.94
21	113.149	80.802	72.649
24	102.903	70.484	65.819
27	89.448	58.63	59.883
30	72.249	55.723	56.84
33	63.679	53.796	49.532

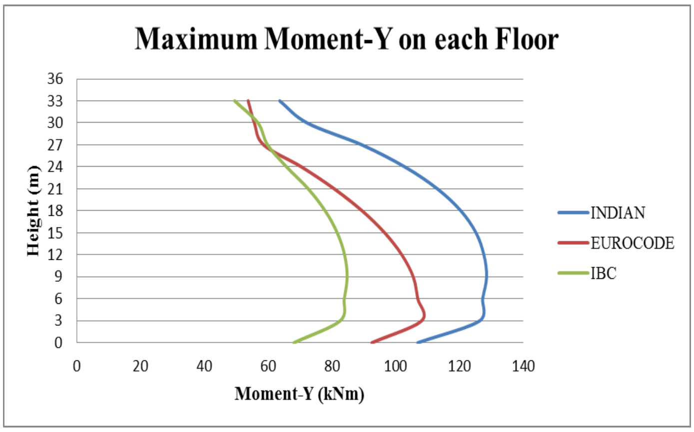


Fig-2.4.3: Maximum Moment-Y on each floor

2.4.4 Maximum Moment-Z on each Floor

Table-14: Maximum Moment-Z on each floor

Height (m)	Maximum Moment-Z on each Floor		
	INDIAN (KNm)	EUROCODE (KNm)	IBC (KNm)
0	155.732	135.365	99.248
3	147.644	126.275	92.687
6	146.571	122.048	91.021
9	148.577	122.39	92.466
12	149.958	119.673	91.576
15	148.718	114.601	88.838
18	144.655	107.37	84.372
21	137.477	98.093	78.236
24	126.726	86.763	72.237
27	112.705	73.88	68.722
30	90.688	59.728	65.774
33	86.189	55.926	53.918

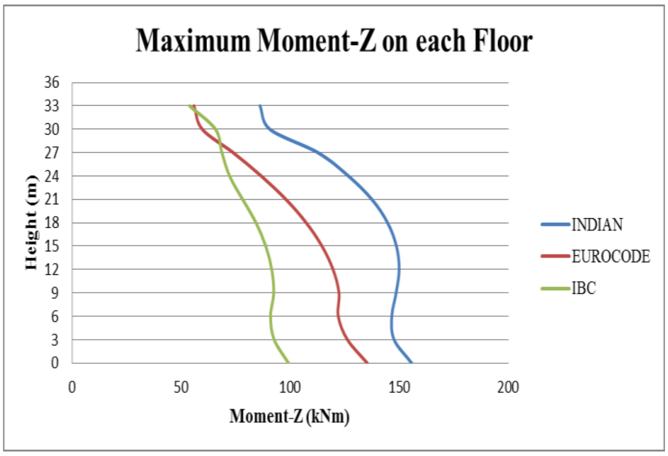


Fig-2.4.4: Maximum Moment-Z on each floor

2.5 BEAM

2.5.1 Maximum Displacement on beam at each floor

Table-15: Maximum Displacement on beam at each floor

Floors	Maximum Displacement on beam at each floor		
	EUROCODE (mm)	INDIAN CODE (mm)	IBC (mm)
GF	4.037	4.406	3.715
3RD	7.842	8.578	7.187
6TH	10.539	11.534	9.647
9TH	11.919	13.05	10.908
11TH	11.119	12.139	10.216
Maximum Displacement (mm)	11.919	13.05	10.908

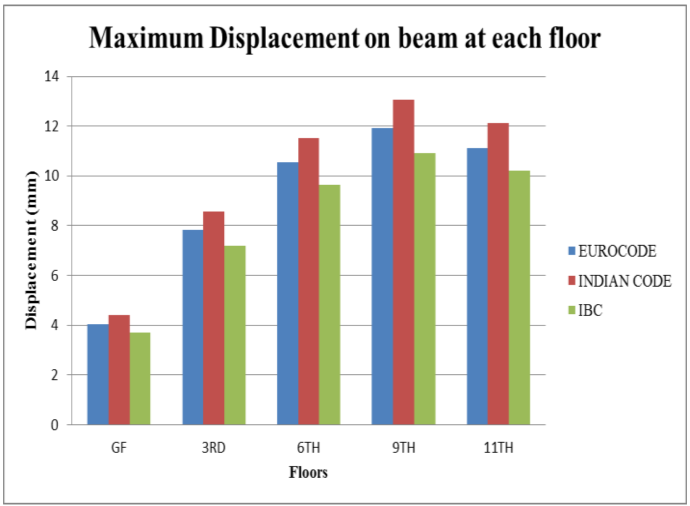


Fig-2.5.1: Maximum Displacement on beam at each floor

2.5.2 Maximum Moment-Z KNm on beam at each floor

Table-16: Maximum Moment-Z on beam at each floor

Floors	Maximum Moment-Z KNm on beam at each floor		
	EUROCODE (KNm)	INDIAN CODE (KNm)	IBC (KNm)
GF	144.515	183.201	148.256
3RD	156.784	203.169	157.999
6TH	140.948	192.894	147.576
9TH	122.63	161.726	127.402
11TH	56.775	83.852	58.695
Maximum Moment-Z (kNm)	156.784	203.169	157.999

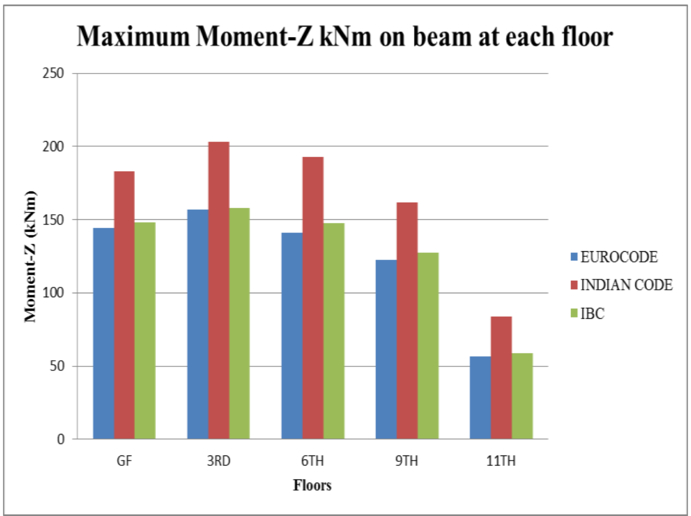


Fig-2.5.2: Maximum Moment-Z on beam at each floor

2.5.3 Maximum Shear-Y KN on beam at each floor

Table-17: Maximum Shear-Y on beam at each floor

Floors	Maximum Shear-Y KN on beam at each floor		
	EUROCODE (KN)	INDIAN CODE (KN)	IBC (KN)
GF	128.451	149.047	110.744
3RD	138.073	169.065	123.47
6TH	119.14	158.218	115.818
9TH	109.756	124.889	101.543
11TH	48.118	61.665	49.988
Maximum Shear-Y (kN)	138.073	169.065	123.47

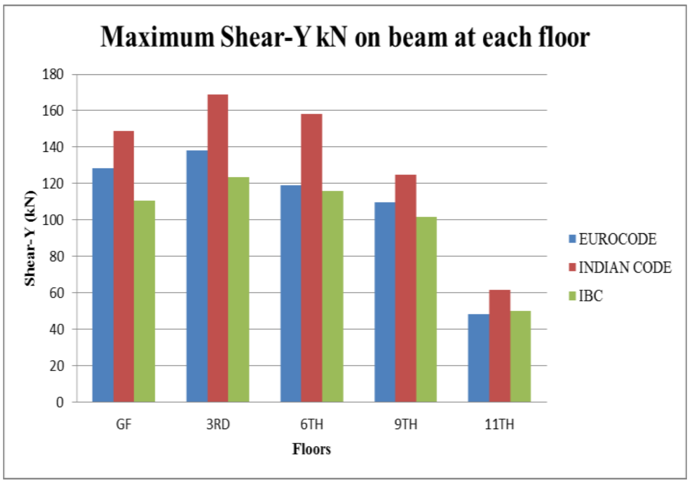


Fig-2.5.3: Maximum Shear-Y on beam at each floor

2.5.4 Maximum Torsion kNm on beam at each floor

Table-18: Maximum Torsion on beam at each floor

Floors	Maximum Torsion kNm on beam at each floor		
	EUROCODE (KNm)	INDIAN CODE (KNm)	IBC (KNm)
GF	18.271	21.599	14.523
3RD	19.837	24.802	15.356
6TH	15.047	20.983	11.679
9TH	7.765	12.686	6.131
11TH	4.138	5.684	4.394
Maximum Torsion (kNm)	19.837	24.802	15.356

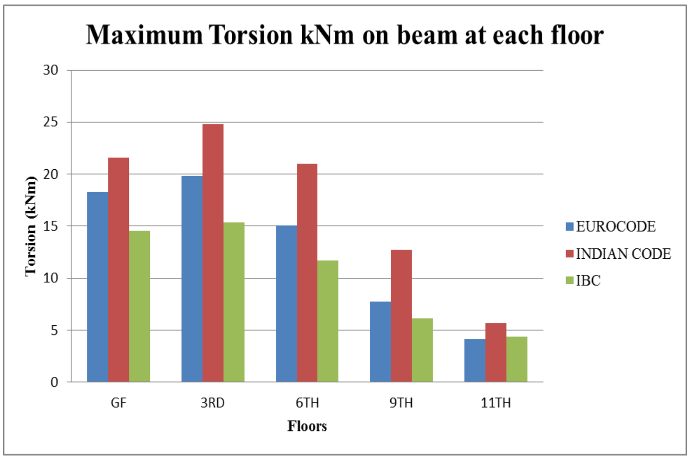


Fig-2.5.4: Maximum Torsion on beam at each floor

3. CONCLUSIONS

1. Base Shear as per three different codes.

- Calculated Base shear in X direction, Compared to Indian code, IBC shows 5.53 % less base shear and Eurocode shows 38.52 % more base shear.
- Calculated Base shear in Z direction, Compared to Indian code, IBC shows 5.7 % less base shear and Eurocode shows 30.47 % more base shear.

2. Displacement, Axial load, Moment for selected columns.

- Displacement as per Indian code is maximum compared to other codes, Displacement as per IBC is 42.44 % less and Eurocode is 23.12 % less value than Indian code.
- Axial force as per Indian code is maximum compared to other codes, Axial force as per IBC is less by 14.3 % and Axial force as per Eurocode is less by 8.52 % as compared to Indian code
- Moment-Y as per Indian code is maximum compared to other codes, Moment-Y is 33.82 % less of IBC as compared to Indian code and 16.54 % less of Eurocode as compared to Indian code.
- Moment-Z as per Indian code is maximum compared to other codes, Moment-Z is 36.27% less of IBC as compared to Indian code and 13.08 % less of Eurocode as compared to Indian code.

3. Displacement, Moment-Z, Shear-Y and Torsion for selected beams.

- Displacement as per Indian code is maximum compared to other codes, Displacement is found to be 16.42 % less as per IBC and 8.67 % less as per Eurocode as compared to Indian code.

- Moment-Z as per Indian code is maximum compared to other codes, Moment-Z is 22.24 % less as per IBC as compared to Indian code and 22.84 % less as per Eurocode as compared to Indian code.

- Shear-Y as per Indian code is maximum compared to other codes, Shear-Y is 26.97 % less as per IBC as compared to Indian code and 18.34 % less as per Eurocode as compared to Indian code.

- Torsion as per Indian code is maximum compared to other codes, Torsion is 38.09 % less as per IBC and 20.02 % less as per Eurocode as compared to Indian code.

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